TITLE: Intersubband Transitions in InGaAs/InAlAs Multiple Quantum Wells Grown on InP Substrate

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# INTERSUBBAND TRANSITIONS IN InGaAs/InAlAs MULTIPLE QUANTUM WELLS GROWN ON InP SUBSTRATE.

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## ABSTRACT

Intersubband transitions in $In_{0.52}Ga_{0.48}As/In_{0.52}Al_{0.48}As$ multiple quantum wells grown on lattice matched InP substrates were investigated using Fourier transform infrared (FTIR) absorption and photoluminescence (FTPL) techniques. The well width was tailored to produce excited states resonant in the conduction band, at the edge of the conduction band, and confined in the quantum wells. Interband transitions were also probed using FTPL and optical absorption techniques. The FTPL spectra show that three interband transitions exist in the quantum well structures with well width larger than 30 Å. The intersubband transitions in this class of quantum wells seem to withstand proton irradiation with doses higher than those used to deplete the intersubband transitions in the GaAs/AlGaAs multiple quantum wells.

## INTRODUCTION

Interband and intersubband transitions in bulk semiconductor, multiple quantum wells (MQWs), superlattices, and multiple quantum dots have been the subject of many studies (see for example Refs. [1], [2], [3], [4] and [5]) due to the fact that they form the basis for a new generation of low background and high detectivity very long, long and near wavelength infrared (IR) detectors. Additionally, IR detectors have enabled a new and a wide range of applications even though their potential is not fully realized and explored. GaAs/AlGaAs based multiple quantum well structures are the most mature of quantum well structures and have been widely studied for many applications including IR detectors (see for example Refs. [1], [6], [7] and [2]-[4]. Furthermore, these structures have been used in the development of novel high performance multi-color quantum well infrared photodetector (QWIP) for 3-5 μm mid-wavelength infrared and 8-14 μm long-wavelength infrared detection and to obtain a better understanding of the basic mechanisms that could be used to optimize the performance of these QWIPs. In case of shorter wavelength applications such as 1.55 and 1.3 μm for optical communication, the GaAs/AlGaAs MQWs may not be able to meet the demand since the conduction band offset is too small for a such wavelength range. Thus, there is a need to investigate different quantum structures with larger conduction band offset. InGaAs/InAlAs MQWs have the potential to be used as possible structures for shorter wavelength applications due to the fact that this system can be tailored with a larger conduction band offset.

In this paper, we report on the optical properties of intersubband transitions in InGaAs/InAlAs MQWs grown on lattice matched InP substrates. Photoluminescence spectra were obtained for several samples where the excited state is resonant in the conduction band or confined in the well. Additionally, proton irradiation was performed on the intersubband transition and the results will be discussed.

## EXPERIMANTAL TECHNIQUES

Three $In_{0.52}Ga_{0.48}As/In_{0.52}Al_{0.48}As$ multiple quantum well structures grown on InP substrates were grown by the molecular-beam epitaxy technique. The $In_{.53}Ga_{.47}As$-$In_{.52}Al_{.48}As$ were both lattice matched to the InP substrates with $\Delta a/a$ less than $5x10^{-4}$ in each case . The growth were performed at a temperature of 450 °C which was optimal for this material system. The barrier thickness is 300 Å for all samples and the well width is 30Å, 55Å, and 75Å for the three samples. The well regions were Si-doped {[Si]=$9x10^{18}$ $cm^{-3}$}. The quality of the layers was examined by room temperature Hall effect measurements and the mobility was found 1554, 2324, 2005 μ ($cm^2/Vs$) for the 30Å, 55Å, and 75Å, respectively, while the Hall effect carrier concentration is consistent with growth doping profile (~$9x10^{18}cm^{-3}$). The samples were also irradiated with 1 MeV protons beam. The infrared absorption spectra were recorded at the Brewster's angel of GaAs (73°) from the normal using a BOMEM Fourier-transform interferometer in conjunction with a continuous flow cryostat. The sample's cold finger holder was designed for the GaAs Brewster's angle, but the InP Brewster angel of 71° is very close to that of GaAs. The temperature was controlled within ±1.0 K and the spectra were measured at either 77K or 300K. Interband transitions were measured using the BOMEM spectrometer in conjunction with a PL attachment. Cary 500 spectrometer was also used to measure the band edge absorption of the quantum structures.

## EXPERIMENTAL RESULTS AND DISCUSSIONS

The optical absorption spectra of the intersubband transitions in the three samples are shown in Fig. 1. The spectra are measured at both 77 K and 300 K. It is clear from this figure that the energy separation between the ground and excited states is decreased as the well width is increased from 30 Å [Fig. 1(a)] to 55 Å [Fig. (b)]. As the well width is increased to 75 Å, the structure seems to accommodate more than one excited states with the Fermi energy level being above the fist excited state. Hence one can observe intersubband transitions from the ground state to the first excited state and from the first to the second excited sates. This is illustrated in Fig. 1(c) where two intersubband transitions are clearly visible. From the shape and intensity of the intersubband transitions, one can suggest that the excited state in the sample with 30 Å wells [Fig. 2(a)] is resonant in the conduction band. The asymmetrical shape of the spectra in Fig. 1(b) indicates that the excite state is very close to the top of the barrier conduction band. This is due to the asymmetrical energy levels in the k-space. However, as the excited state is dropped inside the well by increasing its width, the line-shapes of the intersubband transitions become more symmetrical as shown in Fig. 1(c). This strongly suggests that both the ground and excited states have more or less the same

curvature in the k-space or the effective mass of the carrier is almost the same in both the ground and excited states. The positions of the energy levels in $In_{0.52}Ga_{0.48}As/In_{0.52}Al_{0.48}As$ MQWs seems to strongly depend on the well widths as compared to the GaAs/AlGaAs systems [8]. This is may be due to the fact that the conduction band offset in $In_{0.52}Ga_{0.48}As/In_{0.52}Al_{0.48}As$ MQWs is much larger than that of the GaAs/AlGaAs MQWs.

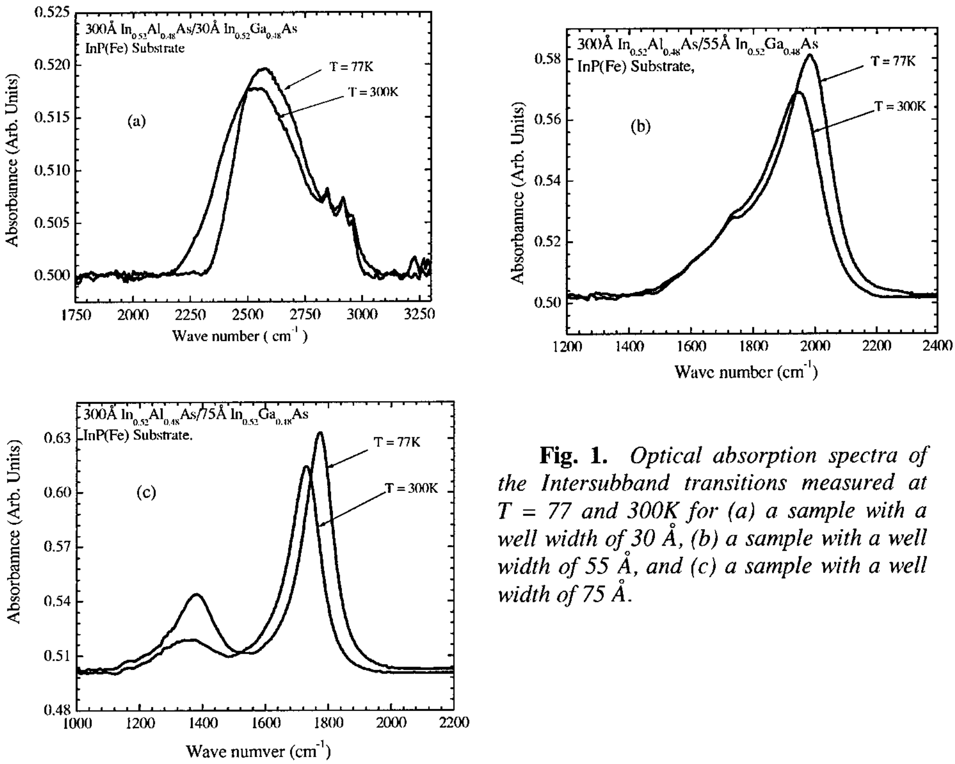
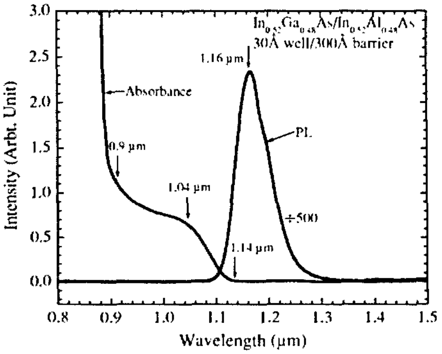
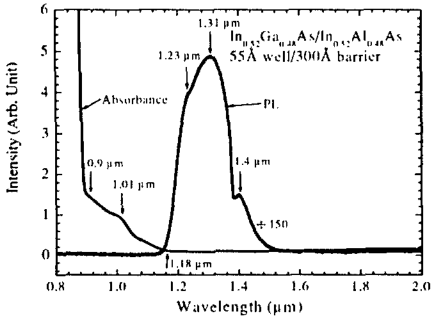



**Fig. 1.** *Optical absorption spectra of the Intersubband transitions measured at T = 77 and 300K for (a) a sample with a well width of 30 Å, (b) a sample with a well width of 55 Å, and (c) a sample with a well width of 75 Å.*

Interband transitions in the three MQW samples were probed using both FTPL and monochromatic light absorption. The results are shown in Fig. 2 where both the band edge absorption and PL spectra overlaid for each sample. The optical absorption threshold seems to be the same for all samples, but the PL spectra consist of only one peak for the sample with a well width of 30 Å, which suggest that there is only one confined state in the conduction band [see Fig. 2. (a)]. The PL spectra for the samples with well widths of 55 and 75 Å show structures with two peaks around 1.4 and 1.3 μm and a shoulder around 1.24 μm. The optical absorption threshold energy is about 1.17 μm (1.06 eV) while the dominant PL peak position energies for the three

samples are 1.16 μm (1.07 eV), 1.31 μm (0.947 eV), and 1.34 μm (0.925 eV). This suggests that the samples possess a small Stokes shift, which could indicate a minimal strain or distortion.



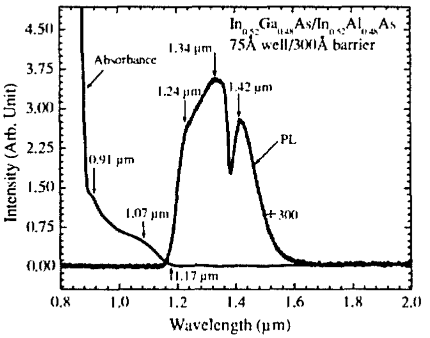




**Fig.2.** *Absorption and PL spectra measured at 10K and 77K, respectively, for the three samples.*

Two of the samples, namely 55 and 75 Å well samples, were irradiated with 1 MeV protons and found that a dose of up to $3\times10^{14}$ $cm^{-2}$ did not seem to produce a significant change in the intensity of the intersubband transitions in the samples. The results are shown in Fig. 3. Recently, proton irradiation effect on the intersubband transitions in GaAs/AlGaAs multiple quantum wells was reported [9]. It was shown that the intensity of the intersubband transitions is decreased as the proton irradiation dose is increased, which was explained in terms of trapping the two-dimensional electron gas in the GaAs quantum wells by the irradiation induced-defects such as vacancies, antisites, and more complex defects. A reduction of the intensity of the intersubband transitions in electron irradiated GaAs/AlGaAs multiple quantum wells was also observed [10] with similar results. It is noted that the intersubband transition in GaAs/AlGaAs to drastically decrease and completely deplete when the GaAs/AlGaAs MQWs where irradiated with 1MeV and a dose of $1\times10^{14}cm^{-2}$. In the present samples, a dose of $3\times10^{14}cm^{-2}$ did not seem to cause the same effect which indicates that InGaAs/AlGaAs is more radiation hardness as compared to GaAs/AlGaAs systems. This subject is still under further investigation.

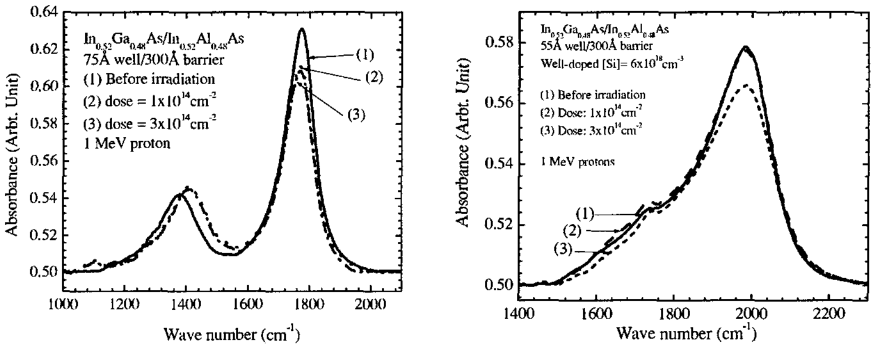



***Fig. 3.*** *Proton Irradiation effect on the intersubband transitions in two InGaAs/InAlAs MQWs samples. Less that 5% reduction was observed in the samples after irradiating them with 1 MeV protons and a dose of* $3x10^{14}cm^{-2}$.

## CONCLUSIONS

Intersubband transitions in InGaAs/InAlAs MQWs grown on lattice matched InP were investigated using optical absorption and photoluminescence technique. The results show that the MQWs exhibit one intersubband transition in samples with a well widths smaller than 55 Å. Two intersubband transitions, on the other hand, where observed in a sample with a well width of 75 Å suggesting that two excited states are confined in the well and the Fermi energy level is above the first excited state. The small difference in the interband transition energies observed by both the optical absorption and photoluminescence techniques suggest a small Stokes shift, which is an indicative of minimal strain. 1MeV proton irradiation yields a small effect on the intersubband transitions in the MQWs up to a dose of $3x10^{14}cm^{-2}$.

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